2021

AP® CollegeBoard

AP® Chemistry

Sample Student Responses and Scoring Commentary

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Free Response Question 4

- ☑ **Scoring Guideline**
- ☑ **Student Samples**
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Question 4: Short Answer — 4 points

(a) For the correct calculated value with units: **1 point**

$q = mc\Delta T = (15.0\text{ g})(0.72\text{ J/(g}\cdot{}^\circ\text{C}))(39.7^\circ\text{C} - 22.0^\circ\text{C}) = 190\text{ J}$

(b) For the correct calculated value of the moles of reaction, consistent with part (a) (may be implicit): **1 point**

$q_{sys} = -q_{surr}$

$-190\text{ J} \times \frac{1\text{ kJ}}{1000\text{ J}} \times \frac{1\text{ mol}_{rxn}}{-1650\text{ kJ}} = 0.00012\text{ mol}_{rxn}$

For the correct calculated value of the mass of iron: **1 point**

$0.00012\text{ mol}_{rxn} \times \frac{4\text{ mol Fe}}{1\text{ mol}_{rxn}} \times \frac{55.85\text{ g Fe}}{1\text{ mol Fe}} = 0.027\text{ g Fe}$ *(0.026 g if decimals are carried)*

Total for part (b) **2 points**

(c) For the correct answer and a valid justification: **1 point**

Greater than. A greater mass of iron provides a greater number of moles of reaction, which would transfer a greater quantity of thermal energy to the same mass of sand and therefore lead to a greater maximum temperature.

Total for question 4 **4 points**

Begin your response to **QUESTION 4** on this page.

$$4\,Fe(s) + 3\,O_2(g) \rightarrow 2\,Fe_2O_3(s) \quad \Delta H° = -1650\,kJ / mol_{rxn}$$

4. A student investigates a reaction used in hand warmers, represented above. The student mixes $Fe(s)$ with a catalyst and sand in a small open container. The student measures the temperature of the mixture as the reaction proceeds. The data are given in the following table.

Time (min)	Temperature of Mixture (°C)
0	22.0
1	25.1
2	34.6
3	37.3
4	39.7
5	39.4

(a) The mixture ($Fe(s)$, catalyst, and sand) has a total mass of 15.0 g and a specific heat capacity of 0.72 J/(g·°C). Calculate the amount of heat absorbed by the mixture from 0 minutes to 4 minutes.

$m = 0.72 \cdot 15 \cdot (39.7 - 22)$

$m = 190\,J$

(b) Calculate the mass of $Fe(s)$, in grams, that reacted to generate the amount of heat calculated in part (a).

$$\frac{-1650\,kJ}{4\,Fe} = \frac{825}{2}\,\frac{kJ}{mol}$$

$$\frac{0.190\,kJ}{825/2\,kJ} = 0.00046\,moles$$

$0.00046 \cdot 55.85 = 0.0269$

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Continue your response to **QUESTION 4** on this page.

(c) In a second experiment, the student uses twice the mass of iron as that calculated in part (b) but the same mass of sand as in the first experiment. Would the maximum temperature reached in the second experiment be greater than, less than, or equal to the maximum temperature in the first experiment? Justify your answer.

Because the iron is what is reacting, doubling the mass would increase the temperature reached. With more moles of reactant, more heat will be released.

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(a) The mixture ($Fe(s)$, catalyst, and sand) has a total mass of 15.0 g and a specific heat capacity of 0.72 J/(g·°C). Calculate the amount of heat absorbed by the mixture from 0 minutes to 4 minutes.

$q = mc\Delta T$

$q = (15.0g)(0.72 J/g\cdot°C)(39.7 - 22.0°C)$

$q = 191.16J$

$q = 190\,J$

(b) Calculate the mass of $Fe(s)$, in grams, that reacted to generate the amount of heat calculated in part (a).

$\frac{-1650kJ}{1\,mol} \times 4\,mols\,Fe = -6600kJ$

190

190J.

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 4** on this page.

(c) In a second experiment, the student uses twice the mass of iron as that calculated in part (b) but the same mass of sand as in the first experiment. Would the maximum temperature reached in the second experiment be greater than, less than, or equal to the maximum temperature in the first experiment? Justify your answer.

It would be higher, because the amount of heat released is according to the mols of $Fe_{(s)}$, ($\Delta H° = -1650 kJ/mol$), and the more mols of $Fe_{(s)}$, the more heat will be released

Begin your response to **QUESTION 4** on this page.

$$4\,Fe(s) + 3\,O_2(g) \rightarrow 2\,Fe_2O_3(s) \quad \Delta H^\circ = -1650\,kJ / mol_{rxn}$$

4. A student investigates a reaction used in hand warmers, represented above. The student mixes $Fe(s)$ with a catalyst and sand in a small open container. The student measures the temperature of the mixture as the reaction proceeds. The data are given in the following table.

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0	22.0
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(a) The mixture ($Fe(s)$, catalyst, and sand) has a total mass of 15.0 g and a specific heat capacity of 0.72 J/(g·°C). Calculate the amount of heat absorbed by the mixture from 0 minutes to 4 minutes.

$q = mc\Delta T$

$q = 15.0g \cdot .72\frac{J}{g°C} \cdot 17.7°C$

$q = .19\,KJ$

$\Delta T = 39.7 - 22.0 = 17.7$

(b) Calculate the mass of $Fe(s)$, in grams, that reacted to generate the amount of heat calculated in part (a).

$4\,moles\,Fe \times \frac{55.85\,g\,Fe}{1\,mol\,Fe} = 223.4g\,Fe$

$3\,moles\,O_2 \times \frac{32g\,O_2}{1\,mole\,O_2} = 96g\,O_2$

$15.0 \times 69.9\% = 10.5g\,Fe$

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Continue your response to **QUESTION 4** on this page.

(c) In a second experiment, the student uses twice the mass of iron as that calculated in part (b) but the same mass of sand as in the first experiment. Would the maximum temperature reached in the second experiment be greater than, less than, or equal to the maximum temperature in the first experiment? Justify your answer.

Less than because there would not be enough sand to react with the iron.

Question 4

Note: Student samples are quoted verbatim and may contain spelling and grammatical errors.

Overview

Question 4 involves the catalytic oxidation of elemental iron inside a small container of sand to produce Fe_2O_3. Part (a) asks for a calculation of the heat absorbed by the iron/catalyst/sand mixture given the change in temperature of the system (ENE-2.D, 5.F). In part (b), the student must calculate the mass of iron required to generate the amount of heat produced in the previous part. Two points are possible for this part: one for determining the number of moles of reaction (ENE-2.F, 5.F) and one for the calculated mass of iron (SPQ-1.A, 5.F). Part (c) asks the student to predict how the maximum temperature would change, if at all, if the quantity of iron were doubled (ENE-2.D, 2.F).

Sample: 4A
Score: 4

This response earned 4 points. In part (a) 1 point was earned for correctly calculating the heat absorbed with the correct unit. Part (b) earned 2 points. Part (c) earned 1 point for indicating that doubling the mass of Fe increases the moles of reactants and more heat is released, which increases the temperature.

Sample: 4B
Score: 2

This response earned 2 points. In part (a) 1 point was earned for correctly calculating the heat absorbed with the correct unit. Part (b) earned 0 points; the number of moles of reaction is not calculated and the molar mass of Fe is not used to calculate a mass of iron. Part (c) earned 1 point for stating that the temperature would be higher because “the amount of heat released is according to the moles of Fe(s)…and the more moles of Fe(s), the more heat will be released.”

Sample: 4C
Score: 1

This response earned 1 point. In part (a) 1 point was earned for correctly calculating the heat absorbed with the correct unit. Part (b) earned 0 points; the first point was not earned because the number of moles of reaction is not calculated and the second point was not earned because the moles of reaction are not used to calculate the mass of Fe. Part (c) earned 0 points for stating that the temperature would be less than because “there would not be enough sand to react with the iron.”